The PowerMatcher: Smart Coordination for the Smart Electricity Grid

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Summary

MOST OF US are not aware of the electricity we use. We only notice how we are dependent on electricity once it fails, which is fortunately something that does not happen often. In the near future, however, the reliability of our electricity supply will need special attention due to three developments. Firstly, the rapid increase in renewable energy creates a challenge for maintaining the balance of supply and demand in the network. This balance is crucial to keep our lighting on. The second trend is the growing use of electricity, which increasingly drives our aging networks towards overload. Furthermore, part of the electricity generated is becoming distributed: large numbers of relatively small generators — solar panels, small wind turbines and micro-combined heat and power— deliver their energy close to the place of consumption. These generators operate outside the reach of the central coordination within the electricity system.

In the future, to ensure the security of electricity supply a new coordination mechanism is required. The current structure, in which a few large plants follow the total electricity demand will no longer suffice. Due to fluctuations in the supply from renewable sources, it is becoming increasingly difficult to maintain the balance between supply and demand in the electricity system. Therefore, electricity demand will have to follow the supply where possible. That would mean that, for example, a consumer's kitchen freezer would automatically start using electricity the moment the sun starts shining on their rooftop solar panel or when the wind increases at an offshore wind turbine park. At the same time, this new way of automatic coordination should prevent the networks from overloading. By shifting loads away from the moments of high peak demand, available capacity can be used in a smart way. There is, in short, a new smart coordination mechanism to achieve this smart grid.

A group of international partners, have worked in recent years to realise this new coordination mechanism for electricity. The result of that work is the PowerMatcher.

This thesis provides a theoretical basis for the design of the PowerMatcher and an extensive validation through simulation studies and field experiments, including "PowerMatching City". These validation studies show, among other things, that the PowerMatcher enables the integration of renewable energy while, at the same time, mitigates overload situations in the network. The design of the PowerMatcher is based on multi-agent systems which makes the system highly scalable and able to ensure user privacy. The theoretical work brings together elements from electrical engineering, computer science, economics and control. Further, it includes a mathematical proof of the optimal performance of the PowerMatcher.

The PowerMatcher moves the energy consumer to the center. Their role will change dramatically as a result of the above-mentioned developments. Firstly, consumers are also increasingly becoming producers of electricity. This is called a prosumer: sometimes a consumer and at other times a producer. More than a century, there were only one-directional electricity flows in the electricity networks, and now with the 'consumer' also providing power back to the network it's becoming unidirectional. As a next step, the prosumer will also become a supplier of an electricity flexibility service. Household appliances and industrial installations will flexibly respond to the availability of cheap green electricity as well as to the availability of network capacity. Although not every device is able to shift its electricity use, many devices do have great potential for flexibility. Both in households and in industry, almost all devices having a thermal function can potentially be made flexible: heating, cooling and freezing. There are also many devices that need to complete their task within a certain time window, such as an electric car charging at night to be able to drive in the morning or a washing machine for which the user has set the completion time. Within the time allotted for their task, these devices are able to shift their electricity use.

Thus the operation of the electricity system changes from central control of a relatively small number of large power plants to coordination of large amounts of (sustainable) generators and flexible users. An important requirement for this coordination system is scalability. Maintaining the system's demand and supply balance will involve a huge number of small and medium-sized energy-demanding equipment. Controlling this from a central point will soon reach the communication and computability limits. This scalability problem is even greater in reality as the distributed generators will also play a role in the coordination task.

Computer science, and in particular the area of multi-agent systems, can offer a solution. A multi-agent system is a distributed software system in which so-called intelligent agents are responsible for local sub-tasks, and communicate with each other in order to achieve the higher system goals. A well-designed multi-agent system is an open, flexible and easily expandable ICT system that can properly operate in a highly complex and changing environment. As the local software agents take care of local business, it screens local (and potentially privacy-sensitive) information from the outside world. The PowerMatcher is designed and built based on this multi-agent technology. The result is a mechanism which allows for coordination of a large number of smaller consuming and producing devices without the autonomy and privacy of the owners of these devices becoming compromised.

By using the PowerMatcher, more renewable energy may be integrated in the electricity system. As the system improves the match between supply and demand, better use of available renewable energy can be achieved. This reduces the demand for energy from other sources, such as fossil fuels. A study of the energy consumption of 3000 households in combination with a large (off-shore) wind turbine park clearly shows this. When using the PowerMatcher, it was shown that approximately 65 to 90% of the wind power, which would normally not be used without coordination, could be locally utilised. As a result of this, the usage of power from fossil fuels is reduced by 14 to 21%.

A reaction from energy demand and distributed generators to fluctuations in the supply of renewable energy also improves the value of green power. The low day-ahead predictability of wind generation, for example, results in additional costs assigned through the electricity wholesale markets, the so-called imbalance costs. In two of the field tests performed with PowerMatcher, a wind farm was coupled to a flexible cluster in order to compensate for deviations from the wind power prediction. This reduced the imbalance caused by the wind farm 40 to 60%. This makes an interesting business case for energy suppliers.

Further, it has been shown in the field that the PowerMatcher is able to avoid overloading of electricity networks. By cleverly managing heating systems (micro-CHP and heat pumps) and/or charging electric cars, the daily peak loading could typically be reduced by 30 to 35%. In existing networks, this saves the network operator an expensive network reinforcement, while new networks can be less heavy designed. In one of the cases studied, the network capacity could be designed three times lower through application of the PowerMatcher.

At present, the electricity sector is making clear steps towards the introduction of the smart electricity grid. This is also reflected in the field experiments and demonstrations performed with the PowerMatcher. The first field experiments were carried out by technology parties. Since a few years, however, parties from the electricity chain have also become involved. Network operators and energy suppliers now play an important role. A sign that the market is ready for this technology and the technology is ready for the market. Another important development is the scale of the demonstration projects. The first two field trials, in 2006 and 2007, both involved less than ten flexible home appliances and industrial installations. From 2009 on, PowerMatching City in Hoogkerk ran with more than 20 households, while the total number of PowerMatcher-equipped homes will surpass 1000 before the end of 2013. These are 40 homes in Hoogkerk, nearly 300 in the Couperus Smart Grid project in The Hague and another 700 in the EcoGrid project in Denmark. More projects are in the preparatory phase.

With a number of industry partners, TNO is working on an open standard on the basis of the PowerMatcher. Through an industry alliance, the Flexible Power Alliance Network (FAN), the PowerMatcher will be made available for the market.